

The Closed String Tachyon and its relationship with the evolution of the Universe

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We present a cosmological landscape where the classical closed string tachyon field plays an important role in the framework of a critical bosonic compactification. Our cosmological solutions for a universe with constant curvature describes an finite inflationary stage which expands till a maximum value before undergoes a big crunch as the tachyon reaches the minimum of its potential.

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I. INTRODUCTION

The tachyon field cosmological models inspired by string theory has generated a great deal of interest over the last few years (see for example Refs. [1]). Some progress has been made in developing a effective theory in the context of open strings, taking into account the minimal state of energy towards the tachyon rolls down to the minimum of the potential, point in where the perturbative approach of the theory becomes reliable. This process is so-called tachyon condensation. Nonetheless, it has been proposed that tachyon condensation could provide a sinewy resolution of cosmological singularities [2].

However, we reminding the reader that tachyonic modes are not exclusively related to open strings only. Closed string tachyon has also generated a great speculation. This kind of modes arise in the bosonic string spectrum and at orbifold singularities within the context of superstring theory. The process which leads the closed string tachyon condensation is nicely described by a tachyonic potential which form has been inferred from String Field Theory (SFT) and it is given by a nicely potential form $V(T) \sim -c_1^2 T^2 + c_2^2 T^4$, where the maximum of the potential occurs at $T = 0$. At this point we can ask whether any effects can arise when the source of tachyonic modes disappear, i.e., if the space-time can collapse itself. It is then natural to imagine an scenario with this kind of potential and expected that can be related with an inflationary universe which collapses as the tachyon condensates. Studies in this matter have been performed through the last few years as was showed in Refs. [3]. Nonetheless, in this models the expansion stage is absent. Therefore, our goal was to found the scenario where an accelerated expansion can be possible.

II. EFFECTIVE CLOSED STRING TACHYON COSMOLOGY

Our alternative starting point is considering the low energy limit of critical bosonic string theory (which implies keeping the dilaton constant Φ_0 and is not dynamically coupled to the scale factor). In this situation we compactified on a 22-dimensional manifold. All this would imply the following Lagrangian[4]

$$\mathcal{L} = \frac{m_p^2}{2} \sqrt{-g^E} [R_4^E + 6(\nabla \ln \Omega)^2 + 6\nabla^2 \ln \Omega + 4(\nabla \Phi)^2 - (\nabla T)^2 - 2\Omega^2(\Psi, \psi)\mathcal{V}(T)], \quad (1)$$

where T is the closed string tachyon field and $\mathcal{V}(T)$ is the effective tachyonic potential \mathcal{V} as $\mathcal{V}(T) = V(T) - \frac{1}{2}R$. g^E is the metric in Einstein frame and Ω is a conformal transformation from string to Einstein frame. Further analysis about it can be found in Ref. [4]. In the rest of this brief paper let us consider the tachyon field to be a function only on time, i.e. $T = T(t)$. Also consider the usual spatially flat FLRW metric $ds_E^2 = -dt^2 + e^{2\alpha(t)}(dr^2 + r^2 d\Omega^2)$. With these arrangements we compute the corresponding equations of motion in the Hamilton-Jacobi formalism,

$$-2 \left(\frac{\partial \mathcal{H}}{\partial T} \right)^2 + 3\mathcal{H}^2 = \mathcal{V}(T). \quad (2)$$

As a next step we want to study under which conditions this formulation describes an universe which inflates and collapses as the tachyon runs down to the minimum of its potential, as expected from the closed string tachyon framework.

III. INFLATION STAGE

Recall that the Hubble parameter H determines the factor scale dynamics and choosing a specific tachyon

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potential constraints it. Without losing this thought, we consider a polynomial H in order to have a SFT-potential of the form: $H(T) = -\frac{1}{2}(A + BT^2)$. The main point in this line is when $A = 0$, in where the SFT-potential is compatible with a effective scalar field only if the internal manifold is flat. In this case the universe acquire a scale factor $a(t) = \exp(-\frac{\Omega}{8}e^{4\Omega Bt})$, where for $B > 0$ describes an universe which starts at $t \rightarrow -\infty$ with $a = 1$ and it always contracts.

Now, within this context, we are capable to compute in the general case the necessary and sufficient conditions for inflation given by $\epsilon \ll 1$ and $\eta \ll 1$ where

$$\epsilon(T) = 2 \left(\frac{H'}{H} \right)^2 = \frac{8T^2}{(A/B + T^2)^2}, \quad (3)$$

$$|\eta(T)| = \left| \frac{1}{\mathcal{V}} \frac{\partial^2 \mathcal{V}}{\partial T^2} \right| = \frac{|(3A - 4B)B + 9B^2T^2|}{|\frac{3}{4}(A + BT^2)^2 - 2B^2T^2|}. \quad (4)$$

Two important aspects to be mentioned form here is that:

- From string theory it is expected that $A \gg 1$, i.e., high curvature of the internal space. This follows from the fact that $R \sim A^2 \sim R^{-6}$, where R is the size of the extra dimensions.
- Fixing A and B for guaranteed an inflation stage implies that the ratio between this values determines how fast the universe expands/collapses.

IV. COLLAPSE STAGE

According to the standard cosmological model, assuming an universe filled by a perfect fluid EoS $p = w\rho$ in our

closed tachyon landscape can show that p is maximum at the minimum of the $\mathcal{V}(T)$. The closed tachyon EoS is

$$w = \frac{\frac{1}{2}\dot{T}^2 - \mathcal{V}(T)}{\frac{1}{2}\dot{T}^2 + \mathcal{V}(T)} = -\frac{8B^2(\Omega^2 + 1)T^2 - 3(A + BT^2)}{8B^2(\Omega^2 - 1)T^2 + 3(A + BT^2)}. \quad (5)$$

Interestingly, for early time, $w = -1$ and the tachyon potential evolves as a cosmological constant.

Regarding some specific conditions, we observed that for a particular form of $\mathcal{V}(T)$ the inflationary/expansion/collapse scenario is possible. More details are exposed in Ref. [4].

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